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Environmental impact assessment of urban mobility plan: a methodology including socio-economic consequences

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Abstract

The project objective is to develop an optimized methodology to assess the environmental impacts of urban mobility plans (UMP, in French PDU), taking into account their social and economic consequences. The main proposed methodology is based on a systemic approach: multi-factor (air quality, noise, energy consumption, greenhouse gas emission) numerical simulations with a chain of physically-based models, based on alternative and comparative scenarios. The social and economic consequences of these alternative simulations are assessed by means of econometric models. Two alternative approaches are explored: (i) the use of composite environmental indicators to correlate the sources to the impacts, especially

health impacts, and (ii) the analysis of sample surveys on what makes inhabitants' quality of life, well-being and territorial satisfaction and on citizens' behavioral changes linked to transport offer changes.

Context

Mobility is at the heart of the stakes for urban sustainable development and transportation policies that are set up in cities increasingly incorporate environmental components. Urban mobility plans are, in France, an essential tool of urban mobility policies. Their environmental features have received increasing attention during the last decade, so that environmental impacts assessment of the mobility plan actions is now compulsory.

The research program Eval-PDU was launched from the request by Nantes Métropole, the community of communes of the Nantes urban area, for a methodology allowing to assess jointly the various environmental impacts of the actual (2000-2010) urban mobility plan (UMP) and of the future plan (2011-2020), taking into account their social and economic consequences. This situation is a good illustration of the need of local public authorities for rigorously based tools to assess a series of impacts (air quality, noise, ...) effectively associated with various actions (or groups of actions) they lead. Beyond the monitoring of objective indicators, it is a matter of understanding and quantifying a cascade of physical and social causalities and, further, its consequences for the quality of life and its perception by the inhabitants. The need concerns as much *ex post* evaluations of what has already been done, as *ex ante* evaluations of what is being planned. A first one-year research-action grant with Nantes Métropole allowed to imagine the main features of the methodology and to build up consequently the project research team. Since January 2009 the program is funded for 3 years by the French national research agency (ANR) within its "Sustainable cities" program.

A priori, the proposed methodology is based on the assumption that quantitative environmental impact assessment require alternative, comparative simulations with physically-based numerical models of air quality (pollution emissions and dispersion), noise generation, energy consumption and greenhouse gas (GHG) emissions. For a joint assessment of these different environmental compartments, the simulations must be based on the same situations, hence on a common description of the transport traffic – this requires (i) a multi-modal traffic numerical model allowing to represent the actual traffic flows and their counterparts in alternative, hypothetical situations, and (ii) a full description of these alternative situations or scenarios, compatible with each of the involved numerical models. The so-

cial and economic consequences of the environmental impacts are to be assessed by econometric model calculations based on the results of the physical process simulations.

This approach raises a large number of methodological questions.

- **About scenarios and data:** What is the pertinence of alternative scenarios to render the changes generated by the UMP? Is-it possible to define different situations "everything else identical"? Can they be translated into coherent data sets? What is the availability of these data, which are necessary to run the various models? Especially in the case where the UMP "starting point" has not been defined in advance?

- **About the physical process simulations:** In the present state of urban transport modeling methods, is a multimodal model able to translate the different scenarios in significant changes of vehicle fluxes and travelled distances? Are multi-factor simulations possible with several mono-factor models? Considering the data and modeling uncertainties, will the simulation results be significant?

- **About the consequence analyses :** Can the simulation results be combined in an integrated assessment? By means of composite indicators? or by "socio-economic" analyses? Are the health impacts identifiable et quantifiable or masked by non-environmental influences? Are the social and economic consequences of environmental impacts of a lower order of magnitude than the direct social and economic impacts? Can they be evaluated in terms of well-being and satisfaction of UMP actions without a full economic computation of the whole UMP?

- **About the methodology itself:** Is-it possible to shorten the long chain of numerical models by using integrated, composite indicators relating the sources (transport fluxes) to the impacts (air quality, nuisances, human health) based on empirical correlations? What is the value of citizen's sample surveys on mobility and behavioral changes in response to mobility offer changes and, since they are more easy to launch by territorial authorities, could they be an efficient alternative?

Project structure

The main approach is based on multi-factor numerical simulations (air quality, noise, energy consumption, GHG emission) representing a set of alternative scenarios (with/without, before/after) rendering the changes in the citizens mobility over the metropolis area generated by UMP actions. These environmental impact simulations require input data sets, among which the emission inventories by the traffic of the different types of transport. Maps of the traffic fluxes are provided by a geographically-

based multi-modal traffic model, whose main part is road traffic which is the key of the environmental stacks. The traffic intensities on the rails and road/street segments are the linear sources in the noise calculations. Combined with an engine emission model, they allow to compute energy consumption and emission inventories of regulated air pollutants and GHG. A urban pollutant dispersion model takes into account the meteorology interactions with the urban morphology to evaluate and map the pollutant concentrations and exposures.

The outputs of these numerical model simulations are the inputs of social and economic consequence calculations. The impacts of air quality and noise are computed on two types of socio-economic indicators: (i) well-being and declared satisfaction indicators, extracted from a survey of 1500 ad-hoc questionnaires to a representative population sample on 8 different districts; (ii) property values of housings, spatially correlated with the transport system main features. Econometric methods are further used to isolate the influence of environmental factors from those of other, preponderant factors.

Two alternative approaches are also explored, aiming at skipping all or parts of the numerical model chaining while keeping the capability of analyzing the processes from the socio-economic point of view. The first method, based on the works of COST action 356, consists in designing composite environmental indicators which correlate the sources and the impacts, i.e. the different transport mode intensities and the environmental quality indices; this method will be especially developed for assessing the health impacts, and compared to the results of the previous method. The second alternative approach consists in evaluating the environmental consequences of the changes in citizens' behavior linked to key UMP actions, from another survey among specific inhabitants especially concerned with these actions, by identifying their individual adaptation strategies to the variations in transport offer.

The program includes a large amount of result analysis and return of experience in view of (1) applying the assessment methodology to the special case of Nantes urban area actual and future plans, (2) revising and optimizing the proposed methodology, (3) taking into account the knowledge obtained from the alternative approaches.

The research program is composed of 11 main tasks: project coordination, construction of alternative scenarios representing UMP actions and methodology optimization, data flux management and storage in a common geographical information system (GIS), multi-modal mobility modeling, simulation of pollutant emissions, GHG and energetic consumption, simulation of air quality, simulation of noise propagation and impacts, so-

cio-economic assessments by econometric and well-being models, assessment by composite indicators, assessment of environmental consequences of the induced changes in citizens' behavior. These tasks are structured into 8 task packages according to their nature and the participation of the eleven research groups.

Coordination, construction of the methodology and scenarios

Coordination

The first task consist in the usual management of the program, including relations with the ANR funding agency, inter-teams and external communications (web, meetings, presentations and publications), and the coordination of the advancement of the different tasks. This last part is especially delicate due to the chaining of the successive modeling tasks and to the relatively large number of young scientists specifically hired for the program. Internal reporting is very important in such a program where several tasks are strongly inter-dependent. The task also includes coordination with Nantes Métropole, which is presently involved in its UMP assessment and revision, and which is the main provider of input data to the research program. Finally it includes coordination with other associated researches as, e.g., a series of student works on the relationships between the UMPs and other local territorial plans for air quality protection, climate, noise protection, ground occupation, and development schemes, and on the "environmentalization" of rules and instruments of urbanism law and land law.

Methodology construction and optimization

The construction of the proposed methodology is a continuous task, from the program start since it is necessary to define the research work, until the end since an optimized methodology is the expected result of the works. A preliminary version will be first established, based on the situation of Nantes Métropole. A further analysis of its assumptions, principles, difficulties, drawbacks, ... will be pursued during the course of the researches, with the aim of adapting the methodology to other urban areas. An optimized version will finally be drafted based on the results and returns of experience of the other task groups.

The task includes first an in-depth analysis of the previous examples of French and foreign UMP assessments, as well as of the relationships between the principles behind the design of the mobility plan of Nantes Métropole and their translation into actions on the transport network.

These actions cover a very large range: infrastructures, parking, urban toll, traffic restrictions, public transport, eco-driving, multi-modal information ... They are categorized as a function of their time-space scales, their mechanisms (actions on behavior, traffic, modal split, prices), and the importance of their expected environmental impact, for selecting the different assessment methods, measurement tools, and pertinence for the urban mobility management.

In the final phase, the experience gained by the different task groups will be integrated to optimize the proposed methodology and to adapt it to either the ex-post assessment of achieved plans or ex-ante assessment of the expected impacts of plans in construction.

Construction of alternative scenarios representing UMP actions

The alternative scenarios are a key to the joint multi-factor impact assessment. For ex-post assessments, they must express the main features of the actual transport system and offers, and those they would have if the UMP actions had not been realized. This implies to select the data sets which define a reference situation "before" the UMP and to imagine the values of these data in situations "without" the UMP but taking into account all the changes which are not related to the UMP actions as, e.g., gas and energy price variations, urban sprawling, local and national economic transformations ... Furthermore these data sets must be effectively available for the representative time horizons, e.g. just before and after the period of the plan, or a reconstruction method must be designed.

This task objective is to formulate the methodological principles of construction of alternative scenarios for environmental impact assessment. These principles are further applied to the main actions of Nantes UMP, and their feasibility and effectiveness are analyzed. In a further stage, the additional assumptions which are necessary to define the model input data sets will be explicitly described.

The chain of physical process models and data flux management

Data acquisition, repository and GIS

The data flux is an important key of the proposed methodology since many model inputs are some outputs of the previous calculations. The uniqueness and/or coherency of input data is also a key of the joint multi-factor assessment. All the data obtained from external sources are stored in a common repository geographical information system based on the open

source platform OrbisGIS developed byIRSTV for urban researches. Further, all model outputs are stored in this GIS prior to their further use as inputs of other models, ensuring spatial coherency and quality control.

The common GIS construction includes a spatial semantic, definition of common mapping modes, adapted geo-statistical calculation and representation tools. It allows direct comparison, superposition, and fusion of results from the various tasks. It is also a powerful tool for the presentation of the program results.

Multi-modal mobility

The model calculations include two parts: transport offer and transport request.

The multi-modal traffic software VISUM is used to compute the traffic over the road and public transport networks. The calculation domain has an area of 2242 km²; 300 traffic zones have been defined with a grid density increasing towards the city centre. The simulation includes explicit calculation of inter-zone traffics over 4100 street segments (2300 km, i.e. 25 % of the total) and calculation with an implicit method for intra-zone traffics. It separates heavy duty (HD) and light duty (LD) vehicles, computes transport by trains, trams and buses over the whole network, and includes free and toll parking possibilities, including modal exchange P+R, but not bikes and motorbikes. Modal split procedures involve walking courses.

The model calculations are driven for 4 periods of the average week day: morning peak (7–9 am), evening peak (5–7 pm), night (8 pm – 6 am) and the rest of the day. Long term integrations thus require weighting factors for vacation periods and week-ends. The model outputs are traffic densities, fluxes and speeds over the segments, journey times and costs as a function of transport mode and population type.

The reference situation for transport request is the transport-population sample survey of 2002 over the metropolitan area, completed by regional social and economic data bases estimated for the same year. These data are analyzed with the software VISEM to produce origin-destination matrixes, using transportation times calculated by VISUM. New simulations will also be run for 2008, based on the data from a national survey and local counting, with various options and scenarios.

Noise propagation and impacts

The noise propagation calculations are based on the equivalent point source method where each actual source is modeled by one or several (en-

gine, wheels) point sources characterized by a sound spectrum, a height and a directivity. The calculations are limited to light vehicles and trams in the first stage, then extended to buses and eventually to motorbikes (which are not well documented yet). Street and track segments appear as lines of point sources function of traffic intensity and vehicle types.

The propagation calculations include direct, reflected and diffuse components, towards a regular grid of virtual receptors. They are implemented as a plug-in within OrbisGIS, allowing to handle the sources, the calculations, and the representation of results with a unique software.

The results are maps of integrated indicators as, e.g. the equivalent continuous sound level L_{eq} , for standard periods of time in the days.

Pollutant emissions and energy consumption

The emission inventories are computed with two methods in parallel, COPERT 4 and ARTEMIS, which have been developed by the European Environmental Agency and the European DG TREN, respectively [1]. COPERT 4 is based on a collection of standard emission factors for the different classes of vehicles, propellants, loads, speeds, for a large number of pollutants [2]. Adjusted to the French vehicle fleet, and applied to the traffic cadastres they are used here to compute the emissions of CO, NO_x, NMVOCs (incl. Benzene, Toluene, Xylene), formaldehyde, SO₂, CH₄, CO₂, N₂O, NH₃, PM₁₀, PM_{2,5}, PM₁, Total particles, PAHs, POP, dioxins, furans, and toxic metals. The energy consumptions are also an output of the calculations.

While COPERT 4 calculations are based on average vehicle speeds, the ARTEMIS method is more dynamic, taking into account the characteristics of each segment (zone, type, slope) and the speed profiles corresponding to instantaneous traffic conditions (fluid, dense, saturated, congested) [3]. This tool includes EURO4 regulation and the further reduction rates. It is being adjusted to the French vehicle fleet and adjustment hypotheses for the Nantes area are being formulated.

The inventory of non-traffic sources (combustion and solvents) is constructed from national and regional consumption data bases using a top-down approach based on population densities (residences and offices density and characteristics) at the scales of communes, districts and blocks.

Air quality

The urban pollutant dispersion model ADMS Urban has been selected from 8 model intercomparison studies [4]. Based on emission inventories, the model is tested and adjusted to the pollutant concentration measure-

ments of the air quality survey network Air Pays de la Loire for the reference years 2002 and 2008.

The UMP impacts on air quality are assessed by comparisons of pollutant concentrations over the Nantes Métropole area and within a selection of streets of the city center during the final year for the scenarios with UMP actions versus "business as usual".

Socio-economic assessments

This task includes a close cooperation of economists, geographers, sociologists and geomaticians to identify and produce pertinent and tractable geographical indicators. The developments are included in OrbisGIS, with the socio-economic data bases. Several population distribution and well-fare data bases of INSEE (National institute of statistics and economical studies), at different dates from 1990 to 2006, are used to characterize the population of Nantes sectors and districts in view of establishing representative samples.

Well-being and territorial satisfaction

The assessment of the air quality and noise impacts on the population well-being is based on an ad-hoc sample survey of citizens' declared environmental satisfaction linked to the UMP actions. A first 30-90 minutes in-depth interview has been applied to a sample of 40 inhabitants of 7 districts during the 2009 spring, bearing on 5 topics: (i) residential choices and territorial satisfaction; (ii) well-being feeling; (iii) environmental experiences and practices; (iv) spatial practices; (v) relationship to public action.

The theoretical and efficiency analyses of this test survey allowed to define a more elaborated questionnaire and a survey protocol which was first tested on a sample of 30 inhabitants, then applied to 1500 inhabitants of 8 districts during the 2010 spring. The districts are different regarding to the socio-economics characteristics of the population (e.g., repartition of the socio-professional categories), environmental amenities (e.g., distance to the city centre, transports offer, access to green spaces), and morphology (e.g., density, age of the building).

Property values of housings

The study requires to identify the environmental variables which may influence the property prices. The PERVAL data base, which includes the

housing property transactions and prices in the urban area of Nantes, has been included into the communal GIS, and a preliminary analysis is conducted with OrbisGIS to select the pertinent data and indicators which will be further used to establish geographical correlations between public and private network changes and property values.

Composite indicators

The alternative method purpose is to replace the alternative numerical model simulations by the construction of composite indicators aggregating individual impact indices, based on typologies of the environmental impacts of transport modes. These include a "scientific", process-based typology and a social, perception-based typology based on existing surveys. The indicators must further be related to the impact sources (emission factors and traffic intensities) by empirical correlations. This approach is based on the works of the European cooperation action COST 356 [4].

The method is applied to obtain an atmospheric pollution health impact indicator, computed from the vehicle emissions of the various pollutants. The computation includes weighting factors which are functions of the pollutant toxicity levels and of the population exposure levels, based on the existing health impact studies and life time analyses.

Changes in citizens' behavior

The objective of this task is to identify (i) the individual strategies to adapt to transport offer variations issued of some UMP actions, by taking explicitly into account the determining factors of families' time management strategies, (ii) and the types of journeys and populations which are the most sensitive to these variations, and to deduce the consequences for (iii) the environment, and (iv) the public politics. The study focus is the incidence on individual car traffic of the UMP main actions aiming at promoting a modal transfer, since it is difficult to assess their efficiency at fulfilling their objective, generating longer routes, or just reducing mobility.

The analysis is based on two sample survey of selected populations: (i) reduced mobility persons, and (ii) selected users of the public and private transport systems. The task includes the construction and tests of questionnaires and survey protocols, and their application to about 1000 persons at key sites as, e.g., train and tram nodes, city center parking tolls, modal transfer P+R.

Conclusion

The Eval-PDU program is a deeply interdisciplinary program in which scientists of environmental, engineering, and social sciences cooperate tightly to construct a methodology based on the systemic approach. The construction of a methodology involving the assessment of the physical changes induced by the action of a mobility plan in the traffic of the different transport modes, of their environmental impacts, of their social and economic consequences requires a set of scientists who are not used to work together and this in turn requires a strong effort at constructing a common language, at understanding very alien points of view and at accepting very different working methods. A side benefit is a deep enrichment of each other's thoughts.

At the time of this communication the research program reaches mid-way. Most of the "individual" contributions have already been produced or they will be soon, and are now being proceeded in a continuous process; the time of confrontations, revisions, optimizations is coming; this phase is to be driven in common by all participants, with a constructive perspective, and this may not be the easiest and most smooth task.

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